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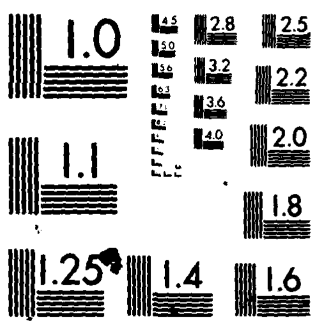

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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

EFFECT OF FREESTREAM RADIAL VELOCITY COMPONENT ON HYDRODYNAMIC ANALYSIS OF PROPELLERS

BY

TERRY BROCKETT

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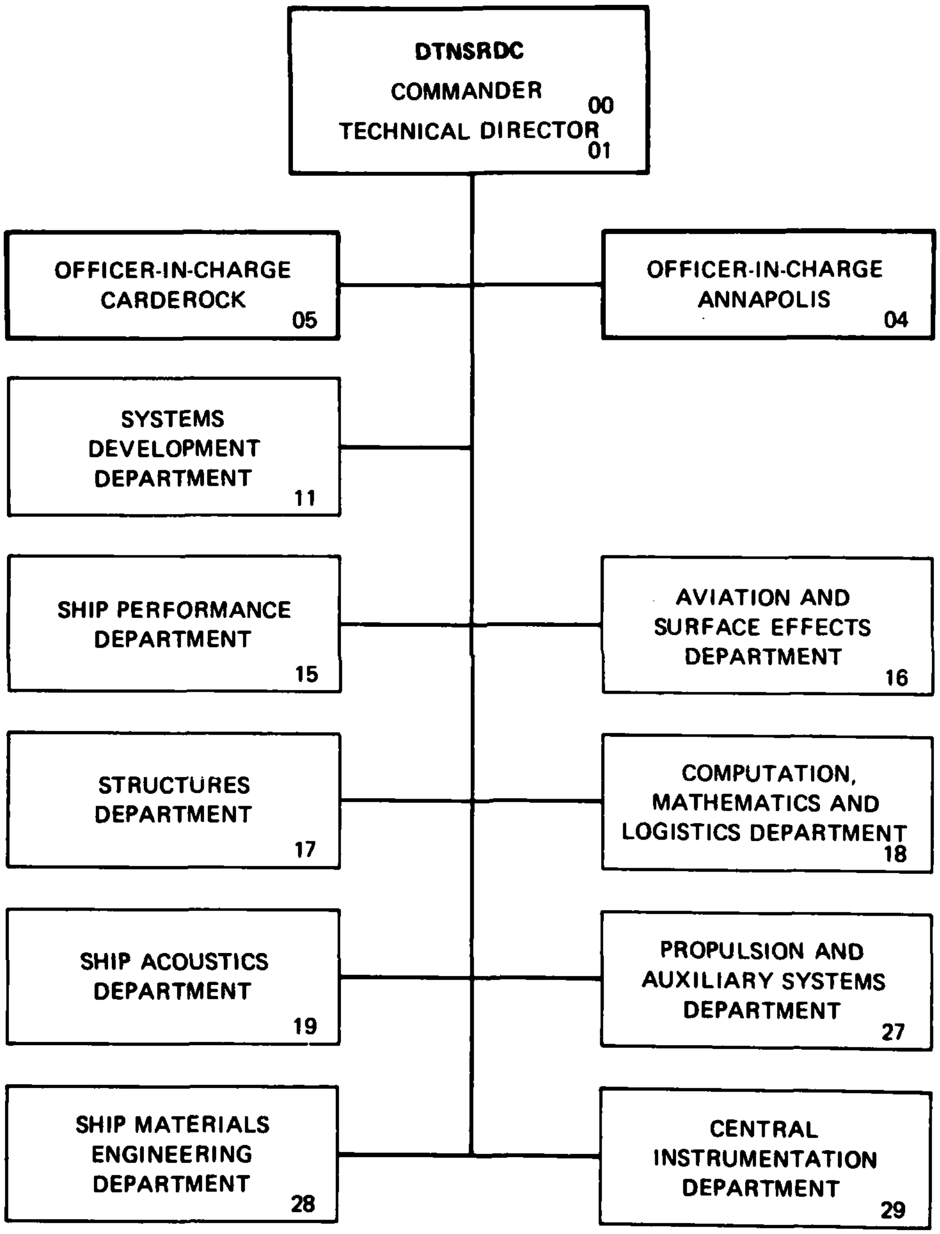

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For wake fields with circumferential averages that include a small radial component, an additional term arises in the mathematical model used for design or performance prediction of propellers that has been previously overlooked. This term arises from the boundary condition that the blade is impenetrable and is a function of only geometry and the inflow radial velocity component. This simple additional term is shown to be important for the example considered, leading to a variable change in camber and a pitch reduction.

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NOMENCLATURE

$c(x_R)$	Propeller blade-section chord length
D	Propeller diameter
$E(x_c, x_R)$	Profile shape function, $E_C \pm E_T$
$E_C(x_c, x_R)$	Meanline shape function
$E_T(x_c, x_R)$	Thickness shape function
$(\underline{e}_1, \underline{e}_2, \underline{e}_r)$	Unit base vectors in a helical reference system
$f(x_R)$	Camber of blade-section meanline
$i_T(x_R)$	Total Rake; axial displacement of blade section midchord point from propeller plane
$(\underline{i}, \underline{e}_r, \underline{e}_\theta)$	Unit base vectors in a cyclindrical polar reference system
$(\underline{i}, \underline{j}, \underline{k})$	Unit base vectors in a cartesian reference system
J	Propeller advance coefficient, $V/(nD)$
$\underline{N}(x_c, x_R)$	Vector normal to blade surface, pointing into fluid
$N_R(x_c, x_R)$	Radial component of $\underline{N}$
$\underline{N}_o(x_c, x_R)$	Normal to blade reference surface (E = 0 surface)
n	Propeller rotational speed, revolutions per unit time
$P(x_R)$	Pitch of propeller blade section
$\underline{q}$	Velocity vector, $\underline{q}_o + \underline{v}$
$\underline{q}_o$	Velocity vector in absence of propeller
$\underline{s}(x_c, x_R)$	Position vector of point on blade surface
V	Propeller reference speed
$\underline{v}$	Velocity component due to presence of propeller
$w_x(x_R)$	Local wake fraction in axial direction at propeller plane

$w_R(x_R)$	Radial component of inflow velocity at propeller plane, fraction of V
(x, y, z)	Cartesian coordinates
x_c	Fraction of chord, measured from leading edge
x_R	Fraction of tip radius, measured from axis of rotation
Z	Number of blades
$\alpha(x_R)$	Angle-of-attack of blade section due to radial inflow
$\beta(x_R)$	Advance angle of propeller blade section, $\tan^{-1}\frac{J(1-w_x)}{\pi x_R}$
$\delta(x_R)$	Multiple of camber due to radial inflow
$\theta(x_c, x_R)$	Angular coordinate in cylindrical reference frame, $\tan^{-1}(-y/z)$
θ_b	Angular coordinate of propeller blade-reference line of bth blade, $2\pi(b-1)/Z$
$\theta_s(x_R)$	Skew angle
$\theta_o(x_c, x_R)$	Angular coordinate of point on blade reference surface
(ξ_1, ξ_2, r)	Helical coordinate on pitch reference surface
$\phi_p(x_R)$	Pitch angle of blade reference surface,

ABSTRACT

For wake fields with circumferential averages that include a small radial component, an additional term arises in the mathematical model used for design or performance prediction of propellers that has been previously overlooked. This term arises from the boundary condition that the blade is impenetrable and is a function of only geometry and the inflow radial velocity component. This simple additional term is shown to be important for the example considered, leading to a variable change in camber and a pitch reduction.

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INTRODUCTION

The hydrodynamic basis for propeller design and analysis is now at such an advanced state and design requirements so precise that factors having known but presumed small effects are being evaluated for their influence on propeller performance. One example of these factors is the Reynold's number influence on the inflow velocity field investigated by Huang and Cox.[1]

In this note, another addition to the design and analysis of propellers is discussed, namely the influence that a small radial component in the inflow to the propeller has in producing a change in the meanline as a result of satisfying the no-penetration boundary condition on the blade surface. In the following

sections of this note, this influence is first analyzed and then an example demonstrating the magnitude of its effect given.

ANALYSIS

Measured velocity fields in the propeller plane are generally non-uniform spatially. When averaged in the circumferential direction, they may be represented by

$$\frac{\underline{q}_0}{V} = (1-w_x)\,\underline{i} + w_R\,\underline{e}_r \qquad (1)$$

where V is a reference speed, typically the ship speed,

w_x is the local axial wake fraction,

w_R is the local radial wake fraction, and

$\underline{i}$, $\underline{e}_r$ are unit vectors in the axial and radial direction respectively.

In general w_x and w_R will be a function of radius and particular flow field. Measurements by Huang, et al[2], indicate a value of $w_R \approx -0.05$ for a particular body of revolution.

In a coordinate system fixed to the blade, which is rotating at a speed of n revolutions per unit time, the flow field into a propeller in this axisymmetric onset stream will be steady. In such a system, the velocity field in the propeller plane will be:

$$\frac{\underline{q}_0}{V} = \sqrt{(1-w_x)^2 + (\pi x_R/J)^2}\,\{\cos(\phi_p-\beta)\,\underline{e}_1 + \sin(\phi_p-\beta)\,\underline{e}_2\} + w_R\,\underline{e}_r \qquad (2)$$

where $\phi_p(x_R)$ is the pitch angle of the blade reference surface, $\tan^{-1}[\frac{P}{D}/(\pi x_R)]$

$\beta(x_R)$ is the pitch angle of onset flow, $\tan^{-1}[J(1-w_x)/(\pi x_R)]$

x_R is the radius, r, non-dimensionalized by the propeller tip radius, R,

$\underline{e}_1$ is a unit vector along the pitch helix, $\sin\phi_P \underline{i} + \cos\phi_P \underline{e}_\theta$,

$\underline{e}_2$ is a unit vector normal to the pitch angle, on the surface of the cylinder r = constant, $-\cos\phi_P \underline{i} + \sin\phi_P \underline{e}_\theta$.

The position vector of points on the surface of the blade is given by[3] (see Figure 1)

$$\frac{\underline{s}}{D} = \left\{ \frac{i_T}{D} + \frac{c}{D}(x_c - 0.5)\sin\phi_P - \frac{E}{D}\cos\phi_P \right\} \underline{i} + \frac{x_R}{2} \underline{e}_r(\theta) \tag{3}$$

where $i_T(x_R)$ is the total rake,

D is the diameter of the propeller,

$c(x_R)$ is the chord length,

x_c is the fraction of chord measured from the leading edge,

$E(x_c, x_R)$ is the section offset, $E_c \pm E_T$,

$$\theta(x_c, x_R) = \theta_b + \theta_s + 2\,\frac{\frac{c}{D}(x_c - 0.5)\cos\phi_P + \frac{E}{D}\sin\phi_P}{x_R},$$

θ_b is the blade spacing, $2\pi(b-1)/Z$ $(b = 1, 2 \cdots Z)$

Z is the number of blades,

$\theta_s(x_R)$ is the skew angle.

A normal to the blade surface (not a unit vector) may be constructed

$$\underline{N}/D^2 = \pm \frac{\partial \underline{s}/D}{\partial x_c} \times \frac{\partial \underline{s}/D}{\partial x_R} \tag{4}$$

$$= \pm \underline{N}_0/D^2 + \Delta \underline{N}/D^2 \tag{5}$$

where the + sign is associated with the suction side of the blade and the - sign with the pressure side of the blade, and

$$\underline{N}_0/D^2 = \frac{1}{2}\frac{c}{D}\left\{ \underline{e}_2 + H_{R_0}\, \underline{e}_r(\theta_0) \right\}$$

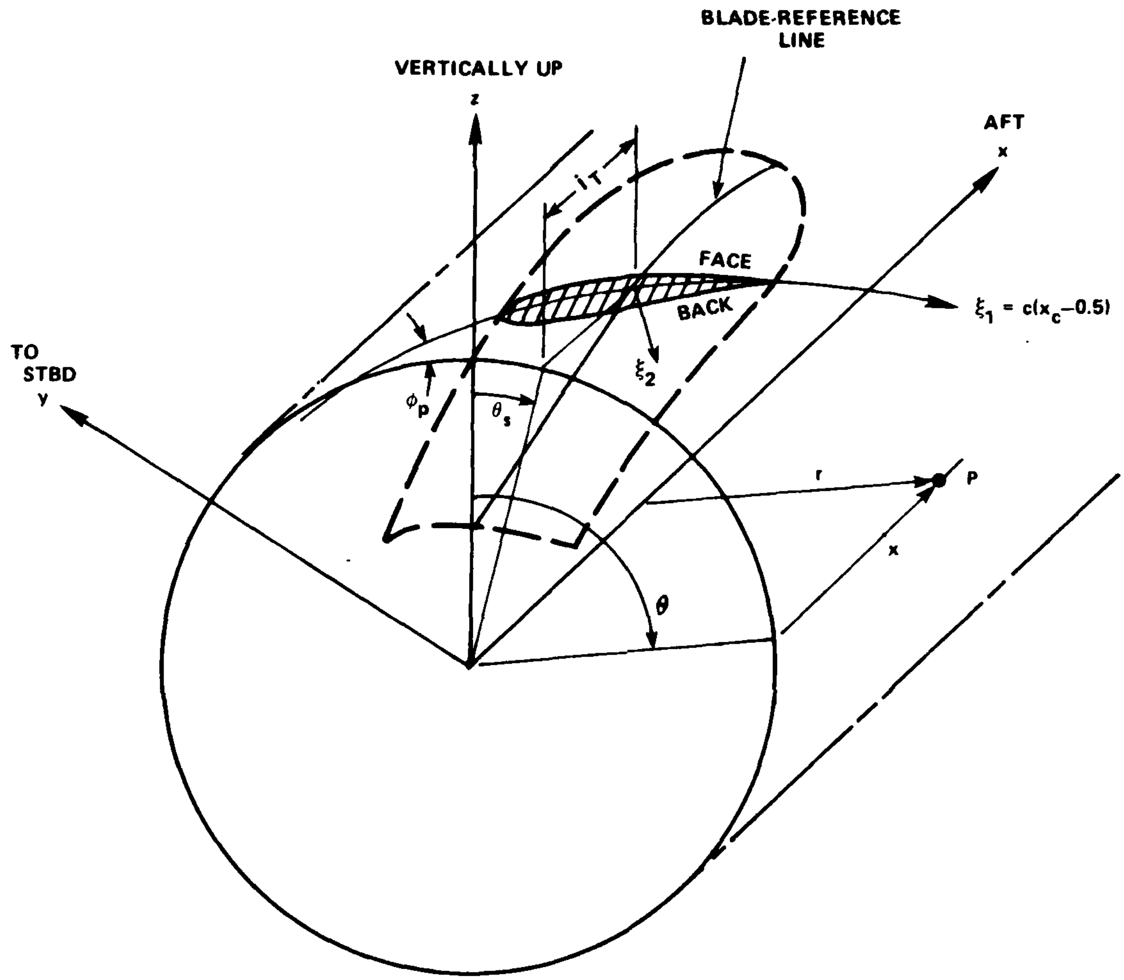

Figure 1 - Propeller Geometry

$$N_{R_o} = 2\frac{d\,i_T/D}{d\,x_R}\cos\phi_P + 2\frac{C}{D}(x_c - 0.5)\frac{dP/D}{d\,x_R}\frac{\cos^2\phi_P}{\pi x_R} - x_R\frac{d\theta_S}{d\,x_R}\sin\phi_P$$

$$\theta_o = \theta_b + \theta_S + 2\frac{C}{D}(x_c - 0.5)\cos\phi_P / x_R$$

$$\Delta \underline{N}/D^2 = -\frac{1}{2}\left(\frac{\partial E_T/D}{\partial x_c} \pm \frac{\partial E_c/D}{\partial x_c}\right)\underline{e}_1 + O\left(\frac{E}{D}, \frac{\partial E/D}{\partial x_c}, \frac{\partial E/D}{\partial x_R}\right)\underline{e}_r$$

The component $\underline{N}_o$ is due to the helical geometry and $\Delta\underline{N}$ is due to the addition of blade-section thickness and camber. In the following development, both ω_R and E/D (which we take representative of $\frac{\partial E/D}{\partial x_c}$ and $\frac{\partial E/D}{\partial x_R}$) are considered small quantities of the same order. We seek the first-order effects of these terms.

The boundary condition on the blade is that no flow pass through the surface. Hence the normal component of the velocity is zero. The total velocity in the rotating coordinate system is the sum of $\underline{q}_o$, the velocity in the propeller plane in the absence of the blades, plus $\underline{v}$, a term arising from the blades:

$$\underline{q} = \underline{q}_o + \underline{v} \tag{6}$$

Hence

$$\begin{aligned} \underline{q}\cdot\underline{N} &= 0 \\ &= (\underline{q}_o + \underline{v})\cdot(\pm\underline{N}_o + \Delta\underline{N}) \end{aligned} \tag{7}$$

Summing the boundary condition on both sides of the blade, one finds

$$\underline{q}_o\cdot(\underline{N}^+ + \underline{N}^-) = -[\underline{v}^+\cdot\underline{N}^+ + \underline{v}^-\cdot\underline{N}^-] \tag{8}$$

Now

$$\underline{N}^+ + \underline{N}^- = \Delta\underline{N}^+ + \Delta\underline{N}^- = -D^2\frac{\partial E_T/D}{\partial x_c}\underline{e}_1 + O(E)\,\underline{e}_r \tag{9}$$

Thus, to first order in w_R and E:

$$[\underline{v}^+\cdot\underline{N}^+ + \underline{v}^-\cdot\underline{N}^-] = -\underline{q}_o\cdot\left[-D^2\frac{\partial E_T/D}{\partial x_c}\underline{e}_1 + O(E)\,\underline{e}_r\right] \tag{10}$$

$$\left.\begin{aligned} &= D^2\sqrt{(1-\omega_x)^2 + (\pi x_R/J)^2}\,\cos(\phi_P - \beta)\frac{\partial E_T/D}{\partial x_c} \\ &\quad + O(E, \omega_R) \end{aligned}\right\} \tag{11}$$

As shown in reference 3, this term gives the source strength of terms representing blade thickness and is here shown to be unchanged to first order by the presence of the radial velocity component.

The difference in boundary condition across the blade is

$$q_o \cdot (\underline{N}^+ - \underline{N}^-) = -\left[\underline{v}^+ \cdot \underline{N}^+ - \underline{v}^- \cdot \underline{N}^-\right] \tag{12}$$

Now

$$\underline{N}^+ - \underline{N}^- = 2\underline{N}_o - D^2 \frac{\partial E_c/D}{\partial x_c} \underline{e}_1 + O(E)\,\underline{e}_r \tag{13}$$

and

$$q_o \cdot (\underline{N}^+ - \underline{N}^-) = 2 q_o \cdot \underline{N}_o - D^2 \frac{\partial E_c/D}{\partial x_c} q_o \cdot \underline{e}_1 + O(E, w_R) \tag{14}$$

Hence to order E or w_R, the meanline slope is

$$\frac{\partial E_c/D}{\partial x_c} = \frac{c}{D}\tan(\phi_P - \beta) + \frac{\underline{N}_o \cdot (\underline{v}^+ + \underline{v}^-)/(D^2 V)}{\sqrt{(1-w_x)^2 + \left(\frac{\pi x_R}{J}\right)^2}\,\cos(\phi_P - \beta)} + \frac{\frac{c}{D} w_R N_{R_o}}{\sqrt{(1-w_x)^2 + \left(\frac{\pi x_R}{J}\right)^2}\,\cos(\phi_P - \beta)} \tag{15}$$

The first two terms on the right hand side have been included in several recent investigations of hydrodynamic propeller analysis.[3,4] The third term is new and we seek here to evaluate its influence.

Let $$E_c = E_{c_o} + \Delta E_c \tag{16}$$

where E_{c_o} results from the existing analysis and

ΔE_c results from the freestream radial velocity component

Hence

$$\frac{\partial \Delta E_c/c}{\partial x_c} = \frac{w_R N_{R_o}}{\sqrt{(1-w_x)^2 + (\pi x_R/J)^2}\,\cos(\phi_P - \beta)} \tag{17}$$

$$= \alpha(x_R) + \delta(x_R)(x_c - 0.5) \tag{18}$$

where

$$\alpha = \frac{w_R}{\sqrt{(1-w_x)^2 + \left(\frac{\pi x_R}{J}\right)^2}\,\cos(\phi_P - \beta)} \left\{ 2\frac{d\, i_T/D}{d x_R}\cos\phi_P - x_R \frac{d\theta_s}{d x_R}\sin\phi_P \right\} \tag{19}$$

$$\delta = \frac{2 w_R\, c/D}{\sqrt{(1-w_x)^2 + \left(\frac{\pi x_R}{J}\right)^2}\,\cos(\phi_P - \beta)} \; \frac{dP/D}{d x_R} \; \frac{\cos^2\phi_P}{\pi x_R} \tag{20}$$

Thus

$$\frac{\Delta E_c}{c} = \int_0^{x_c} \frac{\partial E_c/c}{\partial x_c}\, dx_c \tag{21}$$

$$= \alpha\, x_c - \delta\, \frac{x_c(1-x_c)}{2} \tag{22}$$

Thus the α term, due to variable rake and skew of the blade, results in an angle-of-attack change, and the δ term, due to radially variable pitch, produces a parabolic arc meanline, with a maximum offset at mid chord of

$$\frac{\Delta f}{c} = -\delta/8 \tag{23}$$

For a skewed propeller, the blade sections are displaced aft along the pitch helix passing through a straight radial line and

$$\frac{i_T}{D} = \frac{\theta_s}{2\pi}\,\frac{P}{D} \tag{24}$$

Hence

$$\alpha = \frac{\omega_R\, \theta_s \cos\phi_T}{\sqrt{(1-\omega_x)^2 + (\pi x_R/J)^2}\,\cos(\phi_P - \beta)}\,\frac{1}{\pi}\,\frac{d\,P/D}{d x_R} \tag{25}$$

and for a skewed propeller, both the angle-of-attack term and maximum offset arise because of pitch gradients. For an unskewed propeller, α would be zero, but pitch gradients would lead to a change in the meanline shape.

EXAMPLE

To evaluate the magnitude of the additional term due to a radial velocity component, an example from propeller design will be considered. In Reference 4, Kerwin presents results from a lifting-surface design corresponding to the design requirements for NSRDC Propeller 4498, a propeller with circumferential displacements of the blade mid-chord points but no axial displacement. In Table 1, geometric quantities derived from Table 6 of Reference 4 are given.

Table 1 - Geometry for Design Example

(Propeller Similar to NSRDC Propeller 4498 from Reference 4)

J = 0.888

x_R	C/D	P/D*	$\frac{dP/D}{dx_R}$	i_T	θ_s (RADIANS)	$\frac{d\theta_s}{dx_R}$	$1-w_x$
0.2	0.165	1.163	0.640	0.0	0	1.57	1.0
0.4	0.275	1.260	0.125	0.0	0.314	1.57	1.0
0.6	0.337	1.216	-0.512	0.0	0.628	1.57	1.0
0.8	0.334	1.098	-0.623	0.0	0.942	1.57	1.0
1.0	0	0.974	-0.622	0.0	1.257	1.57	1.0

* Pitch of Reference Surface

Table 2 - Effect of Radial Velocity Component
$w_R = -0.05$

x_R	$\left(\frac{f_o}{c}\right)^{**}_{INITIAL}$	$\left(\frac{P}{D}\right)^{**}_{INITIAL}$	α	δ	$\frac{\Delta f}{c}$	$\Delta\phi_P$ (DEGREES)	$\left(\frac{P}{D}\right)_{FINAL}$
0.4	0.0350	1.511	0.0130	-0.0008	+0.0001	-0.746	1.472
0.6	0.0301	1.292	0.0110	+0.0026	-0.0003	-0.630	1.261
0.8	0.0181	1.065	0.0084	+0.0023	-0.0003	-0.481	1.040

** From Reference 4, lifting-surface design without effect of w_R

In Reference 2, measured values of w_R for a simple body of revolution are given. Although the actual value of w_R is a function of radius, for illustrative purposes this component may be approximated by a constant value of $w_R = -0.05$. Hence α and δ values can be computed from the propeller geometry and this value of w_R. In Table 2, the value of camber and pitch are given as determined by lifting-surface theory[4] without consideration of w_R. In addition, values of α, δ, the change in maximum meanline offset ($\Delta f/c$), change in pitch angle ($\Delta \phi_P$), and final pitch computed by the present analysis are given. The change in pitch angle is important, resulting in a several percent change in the final pitch values.

DISCUSSION

As seen from Table 2, the change in meanline offset is less than one tenth of one percent of the chord and thus a small change. However, the pitch-angle change is about 0.5 - 1.0 degrees and does produce a significant change. Hence this change should be included in propeller designs and performance analysis (as a change in given meanline slope) in order to better model the hydrodynamic flow about propeller blades.

Designs which do not include the effect of the radial velocity component would be overpitched, operate at an rpm less than specified, and with a tendency to have excess camber near the tip. The reduction in pitch would improve the leading edge sheet and tip-vortex cavitation on the suction side and possibly degrade the pressure-side sheet cavitation.

REFERENCES

1. Huang, T.T. and B.D. Cox, "Interaction of Afterbody Boundary Layer and Propeller," Symposium on Hydrodynamics of Ship and Offshore Propulsion Systems, Oslo, Norway (March 1977).

2. Huang, T.T., N. Santelli and G. Belt, "Stern Boundary-Layer Flow on Axisymmetric Bodies," Twelfth Symposium on Naval Hydrodynamics, National Academy of Sciences, Washington, D.C. (1978).

3. Brockett, T.E., "Propeller Perturbation Problems," NSRDC Report 3880 (Oct 1972).

4. Kerwin, J.E., "Computer Techniques for Propeller Blade Section Design," International Shipbuilding Progress, Vol. 20, No. 227, July 1973 and MIT Department of Ocean Engineering (October 1975).

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